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Ryan, R., Gutierrez-Quintana, R., ter Haar, G. and De Decker, S. 'Prevalence of thoracic vertebral malformations in french bulldogs, pugs and english bulldogs with and without associated neurological deficits', *The Veterinary Journal*.

The final version is available online: <http://dx.doi.org/10.1016/j.tvjl.2017.01.018>.

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The full details of the published version of the article are as follows:

TITLE: Prevalence of thoracic vertebral malformations in french bulldogs, pugs and english bulldogs with and without associated neurological deficits

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JOURNAL: The Veterinary Journal

PUBLISHER: Elsevier

PUBLICATION DATE: 31 January 2017 (online)

DOI: 10.1016/j.tvjl.2017.01.018

1 **Original Article**

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4 **Prevalence of thoracic vertebral malformations in French bulldogs, Pugs and English**  
5 **bulldogs with and without associated neurological deficits**

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## 24 **Highlights**

- 25 • Thoracic vertebral malformations are common in neurologically normal French  
26 bulldogs, Pugs and English bulldogs.
- 27 • There is an influence of breed on the prevalence of different types of vertebral  
28 malformations.
- 29 • Hemivertebrae occur more often in neurologically normal French bulldogs and  
30 less often in Pugs.
- 31 • Transitional vertebrae and spina bifida occur more often in neurologically normal  
32 Pugs.
- 33 • Hemivertebrae are more likely to be associated with neurological deficits in Pugs  
34 than the other breeds.

## 36 **Abstract**

37 Congenital vertebral malformations are common incidental findings in small breed  
38 dogs. This retrospective observational study evaluated the type and prevalence of thoracic  
39 vertebral malformations in 171 neurologically normal and 10 neurologically abnormal screw-  
40 tailed brachycephalic dogs. Neurologically normal dogs underwent CT for reasons unrelated  
41 to spinal disease, while affected dogs underwent MRI. Imaging studies were reviewed and  
42 vertebral malformations including hemivertebrae, block vertebrae, transitional vertebrae, and  
43 spina bifida were documented.

44  
45 The group of clinically normal dogs consisted of 62 French bulldogs, 68 Pugs and 41  
46 English bulldogs. The group of affected dogs consisted of one French bulldog and nine Pugs.  
47 Overall, 80.7% of neurologically normal animals were affected by at least one vertebral  
48 malformation. There was a significant influence of breed, with thoracic vertebral  
49 malformations occurring more often in neurologically normal French bulldogs ( $P < 0.0001$ )  
50 and English bulldogs ( $P = 0.002$ ). Compared to other breeds, hemivertebrae occurred more  
51 often in neurologically normal French bulldogs (93.5%;  $P < 0.0001$  vs. Pugs;  $P = 0.004$  vs.  
52 English bulldogs) and less often in neurologically normal Pugs (17.6%;  $P = 0.004$  vs. English  
53 bulldogs). Neurologically normal Pugs were more often diagnosed with transitional vertebrae

54 and spina bifida compared to other breeds ( $P < 0.0001$  for both malformations). Of Pugs  
55 included in the study, 4.7% were diagnosed with clinically relevant thoracic vertebral  
56 malformations. When compared to the general veterinary hospital population, this was  
57 significantly more than the other two breeds ( $P = 0.006$ ). This study indicates that thoracic  
58 vertebral malformations occur commonly in neurologically normal screw-tailed  
59 brachycephalic dogs. While hemivertebrae are often interpreted as incidental diagnostic  
60 findings, they appear to be of greater clinical importance in Pugs compared to other screw-  
61 tailed brachycephalic breeds.

62

63 *Keywords:* Brachycephalic; Hemivertebra; Kyphosis; Spina bifida; Transitional vertebra

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## 65 **Introduction**

66           Congenital vertebral malformations are common incidental findings in small  
67 brachycephalic dogs. Although the terminology used for these malformations is controversial,  
68 they have been classified as defects in segmentation (block vertebrae), defects in formation  
69 (wedge or hemivertebrae) and other defects, including transitional vertebrae and spina bifida  
70 (Westworth and Sturges, 2010). Hemivertebrae are frequently reported in screw-tailed  
71 brachycephalic breeds such as the French bulldog (Moissonnier et al., 2011; Aikawa et al.,  
72 2014; Gutierrez-Quintana et al., 2014). Although the exact aetiology is unclear, they are  
73 assumed to be hereditary (Schlensker and Distl, 2016). These vertebral malformations are  
74 most frequently found in the thoracic vertebral column and can affect single or multiple  
75 vertebrae (Faller et al., 2014; Guevar et al., 2014).

76  
77           Despite the potential to cause clinical signs of spinal cord dysfunction, vertebral  
78 malformations are frequently not associated with disease. Approximately 78% of  
79 neurologically normal French bulldogs had radiographic evidence of hemivertebrae, with or  
80 without spinal kyphosis (Moissonnier et al., 2011). This indicates that caution should be used  
81 when evaluating imaging studies of French bulldogs with suspected spinal disease (Dewey et  
82 al, 2016). More specifically, other spinal conditions, including intervertebral disc disease  
83 (Aikawa et al., 2014) and spinal arachnoid diverticula (Mauler et al., 2014), should be  
84 considered more likely causes of clinical signs in French bulldogs with thoracic vertebral  
85 body malformations. Vertebral body malformations can result in alterations of vertebral  
86 angulation, such as spinal kyphosis and scoliosis. Although the development of clinical signs  
87 in dogs with congenital vertebral body malformations is thought to be multifactorial in  
88 aetiology, it has been suggested that spinal kyphosis is a key factor in the development of  
89 clinical signs and that kyphosis needs to reach a threshold point before clinical signs are

90 likely to occur (Moissonnier et al., 2014; Guevar et al., 2014). Although this situation is well  
91 recognised for French bulldogs (Moissonnier et al., 2011), it is currently unknown if other  
92 screw-tailed brachycephalic dogs demonstrate a similar prevalence of clinically irrelevant  
93 thoracic vertebral malformations.

94

95         The primary aims of this study were to describe and compare the type and prevalence  
96 of thoracic vertebral malformations in French bulldogs, Pugs and English bulldogs with and  
97 without associated neurological deficits. It was hypothesised that although thoracic vertebral  
98 malformations would occur commonly in each of the three evaluated breeds, they would only  
99 rarely result in spinal cord dysfunction. Our secondary hypothesis was that the prevalence of  
100 thoracic vertebral malformations would be breed-associated.

101

## 102 **Materials and methods**

103         The digital medical database of the Small Animal Referral Hospital, Royal Veterinary  
104 College, was reviewed between October 2010 and February 2016 to identify two groups of  
105 dogs. Group 1 included French bulldogs, Pugs and English bulldogs which underwent  
106 thoracic CT under sedation or general anaesthesia for reasons unrelated to spinal disease.  
107 Dogs were excluded if medical records or imaging studies were incomplete or unavailable for  
108 review, or if the dog demonstrated a gait abnormality. A study was considered incomplete if  
109 the complete thoracic vertebral column was not included. Group 2 included French bulldogs,  
110 Pugs and English bulldogs with clinically relevant vertebral malformations diagnosed by  
111 MRI under general anaesthesia. A vertebral malformation had to be the only identified cause  
112 of spinal dysfunction in these dogs.

113

114 Information retrieved from the medical records included signalment, reason for  
115 presentation, results of general physical examinations and, if available, neurological  
116 examinations. CT was performed with a 16-slice helical CT scanner (PQ 500, GE  
117 Healthcare), 2 mm slice thickness and -1 interval between slices After completion of the axial  
118 CT study, sagittal, dorsal and 3D reconstructions were made. MRI was performed with a 1.5  
119 Tesla magnet and included a minimum of T2 –and T1 – weighted sagittal and transverse  
120 images. Slice thickness was 3.5 mm in all planes with an interslice gap of 0.9 mm in the  
121 sagittal planes and 1 mm in the transverse planes. Imaging studies were independently  
122 evaluated by two observers (RR and RGQ for CT studies; RR and SDD for MRI studies),  
123 after which a consensus opinion was reached. The observers were not masked to the breed of  
124 dog. For each imaging study, the number of thoracic vertebrae were recorded and each  
125 thoracic vertebra was subsequently assessed for the presence of hemivertebra, block vertebra,  
126 spina bifida and transitional vertebra (Fig. 1). Hemivertebrae were defined as any defect in  
127 vertebral body formation as outlined by Gutierrez-Quintana et al (2014). Block vertebrae  
128 were defined as failure of vertebral segmentation with absence of the intervertebral disc space  
129 between two adjacent vertebral bodies (Westworth and Sturges, 2010). Spina bifida was  
130 defined as incomplete closure of the vertebral arches resulting in a cleft through the dorsal  
131 spinous process (Westworth and Sturges, 2010). Transitional vertebrae were defined as  
132 thoracic vertebrae at the cervicothoracic or thoracolumbar junctions displaying characteristics  
133 of cervical or lumbar vertebrae, respectively, including the absence or hypoplasia of a rib or  
134 an abnormal transverse process (Westworth and Sturges, 2010). Standard image archiving  
135 and communication system software (Osirix Foundation, V.5.5.2) was used to evaluate all  
136 imaging studies.

137

138 *Statistical methods*

139 Data was analysed using commercial software (IBM SPSS Statistics version 22).  
140 Association between breed and total number of malformations, and the total number of  
141 hemivertebrae and block vertebrae, was evaluated with Kruskal-Wallis tests. Post-hoc  
142 analysis with Mann-Whitney tests was used to determine the relative prevalence in each  
143 breed. The presence of spina bifida and transitional vertebra and the prevalence of clinically  
144 relevant vertebral malformations were determined using Fisher's exact tests; Pugs were  
145 compared to the other breeds as a collective. Values of  $P < 0.05$  were considered statistically  
146 significant for all analyses; the significance level for multiple comparisons was adjusted for  
147 using the Bonferroni method.

148

## 149 **Results**

### 150 *Dogs without neurological signs*

151 A total of 171 dogs, comprising 62 French bulldogs, 68 Pugs and 41 English bulldogs  
152 were included in this group. All underwent CT for a variety of clinical indications, including  
153 brachycephalic obstructive airway syndrome ( $n=124$ ), other respiratory disease, neoplastic  
154 disease ( $n=17$  for both), cardiac disease ( $n=5$ ), gastrointestinal disease, and trauma ( $n=4$  for  
155 both). CT imaging did not reveal any malformations in 33 dogs (19.3%), while single ( $n=36$ )  
156 or multiple ( $n=102$ ) malformations were observed in 138 dogs (80.7%).

157

158 The group of French bulldogs consisted of 52 males and 10 females between 2 and  
159 135 months old (median, 19.5; mean, 29.9 months) and weighing between 6.7 and 16 kg  
160 (median, 11.45; mean, 11.4kg). All French bulldogs had 13 thoracic vertebrae. Four (6.5%)  
161 French bulldogs had no thoracic vertebral malformations, while 58 (93.5%) had one or more  
162 hemivertebrae. A total of 243 hemivertebrae were present; nine (14.5%) dogs had single  
163 hemivertebrae and 49 (79.0%) had multiple hemivertebrae. T9 was most often affected ( $n=31$ )



164 dogs), followed by T10 ( $n=30$ ), T5 and T6 ( $n=29$  for both). Block vertebrae were diagnosed  
165 in four (6.5%) French bulldogs; T11-T12 ( $n=4$ ) were most often affected, followed by T12-  
166 T13 ( $n=2$ ). Fourteen (22.6%) dogs had fused dorsal spinous processes. Transitional vertebrae  
167 were present in three French bulldogs (4.8%). In these dogs, T13 had characteristics of a  
168 lumbar vertebra. Four (6.5%) dogs had vertebrae with evidence of more than one type of  
169 malformation. These consisted of block and hemivertebrae ( $n=3$ ) and spina bifida and  
170 hemivertebrae ( $n=1$ ) combinations. No French bulldogs in this population had evidence of  
171 spinal bifida alone.

172

173 The group of Pugs consisted of 31 males and 37 females between 4 and 151 months  
174 old (median, 31.5; mean, 42.7 months) and weighing between 4 and 14kg (median, 8.15;  
175 mean, 8.3kg). Seventeen (25.0%) Pugs had only 12 thoracic vertebrae. Eighteen (26.5%)  
176 Pugs had no thoracic vertebral malformations. Twelve (17.6%) Pugs had hemivertebrae. A  
177 total of 19 hemivertebrae were present; six (8.8%) Pugs had single hemivertebrae and six had  
178 multiple hemivertebrae. The most commonly affected vertebra was T8 ( $n=8$ ), followed by T7  
179 ( $n=5$ ) and T9 ( $n=3$ ). No Pugs had block vertebrae or fused spinous processes. Transitional  
180 vertebrae were present in 21 Pugs (30.9%). T13 in these dogs had characteristics of a lumbar  
181 vertebra. Twenty-six (38.2%) Pugs had spina bifida. This anomaly was exclusively observed  
182 at T1.

183

184 The group of English bulldogs consisted of 29 males and 12 females between 10 and  
185 132 months old (median, 21.0; mean, 40.9 months) and weighing between 10.3 and 37.1kg  
186 (median, 23.25; mean, 23.9kg). All dogs had 13 thoracic vertebrae. Ten (24.4%) English  
187 bulldogs had no thoracic vertebral malformations. Thirty (73.2%) dogs had hemivertebrae. A  
188 total of 100 hemivertebrae were present; three (7.3%) dogs had single hemivertebrae and 27

189 (65.9%) had multiple hemivertebrae. The most commonly affected vertebra was T9 ( $n=18$ ),  
190 followed by T7 ( $n=14$ ) and T8 ( $n=13$ ). Block vertebrae were diagnosed in four (9.8%) dogs,  
191 with T11-T12 ( $n=3$ ) being most frequently affected, followed by T12-T13 ( $n=1$ ). Eight  
192 (19.5%) English bulldogs had fused dorsal spinous processes. Transitional vertebrae were  
193 present in four (9.8%) English bulldogs. In three of these dogs, T13 had characteristics of a  
194 lumbar vertebra and in one dog, T1 had characteristics of a cervical vertebra. One (2.4%)  
195 English bulldog had evidence of spina bifida at T10. Two English bulldogs had vertebrae  
196 with characteristics of more than one type of malformation, which consisted of transitional  
197 vertebra and hemivertebra ( $n=1$ ) and a transitional and block vertebra ( $n=1$ ).

198

#### 199 *Dogs with clinically relevant vertebral malformations*

200 During the study period, a total of 105 French bulldogs, 192 Pugs and 120 English  
201 bulldogs were presented for a wide variety of clinical indications (neurological and non-  
202 neurological) at the Small Animal Referral Hospital, Royal Veterinary College. Of these  
203 dogs, one French bulldog (0.95% of all French bulldogs presented) and nine Pugs (4.7% of  
204 all pugs presented) were diagnosed with a thoracic vertebral malformation as the cause of  
205 their clinical signs. These 10 affected dogs included eight males and two females, aged  
206 between 4 and 57 months (median, 8.0 months; mean, 20.0). Duration of clinical signs at  
207 presentation varied from 7 days to 2 years (median, 61 days; mean, 173 days) and consisted  
208 of ambulatory paraparesis and ataxia of the pelvic limbs in all dogs. Spinal hyperaesthesia  
209 could be elicited in two dogs. In each of these dogs, thoracic hemivertebrae were the cause of  
210 their clinical signs (Fig. 2). Other abnormalities, not considered to be associated with clinical  
211 signs, included spina bifida at the level of T1 in three Pugs and a transitional T13 vertebra in  
212 two Pugs.

213

214 *Comparison between breeds*

215           There was a significant influence of breed on the overall prevalence of thoracic  
216 vertebral malformations in neurologically normal dogs ( $P < 0.0001$ ). More specifically,  
217 neurologically normal French bulldogs had significantly more thoracic vertebral  
218 malformations than neurologically normal Pugs ( $P < 0.0001$ ). Neurologically normal English  
219 bulldogs had significantly more thoracic vertebral malformations than neurologically normal  
220 Pugs ( $P = 0.002$ ). There were no significant differences between the other individual breeds  
221 ( $P > 0.01$ ). There was a significant influence of breed on the prevalence of hemivertebrae in  
222 neurologically normal dogs ( $P < 0.0001$ ). Hemivertebrae were diagnosed more often in  
223 neurologically normal French bulldogs than in neurologically normal Pugs ( $P < 0.0001$ ) and  
224 English bulldogs ( $P = 0.004$ ). Hemivertebrae were diagnosed less often in neurologically  
225 normal Pugs than in neurologically normal English bulldogs ( $P = 0.004$ ). There was a  
226 significant influence of breed on the prevalence of spina bifida and transitional vertebrae in  
227 neurologically normal dogs, with Pugs significantly more often affected compared to the  
228 other two breeds ( $P < 0.0001$  for both malformations). There was no significant influence of  
229 breed on the prevalence of block vertebrae in neurologically normal dogs ( $P = 0.086$ ).

230

231           Finally, there was a significant influence of breed on the prevalence of clinically  
232 relevant thoracic vertebral malformations, with Pugs being overrepresented compared to the  
233 other two breeds ( $P = 0.006$ ).

234

235 **Discussion**

236           This study described and compared thoracic vertebral malformations in French  
237 bulldogs, Pugs and English bulldogs with and without associated neurological deficits. The  
238 results of this study support previous reports indicating a high prevalence of vertebral

239 malformations in neurologically normal screw-tailed brachycephalic breeds (Moissonnier et  
240 al., 2011; Guevar et al., 2014; Gutierrez-Quintana et al., 2014). Overall, 80.7% of  
241 neurologically normal animals were affected by at least a single malformation and 59.6% had  
242 multiple malformations. This is comparable to previous work reporting a 64.2% prevalence  
243 of multiple thoracic malformations in a population of neurologically normal and abnormal  
244 brachycephalic screw-tailed dogs (Gutierrez-Quintana et al., 2014). This information has  
245 clinical importance for the interpretation of imaging studies in animals with suspected spinal  
246 disease and underlines the importance of questioning the clinical relevance of vertebral  
247 malformations observed on radiological studies. This is highlighted by the fact that, although  
248 thoracic vertebral malformations were commonly encountered on imaging studies, they were  
249 only rarely considered the direct cause of clinical signs in the studied breeds. While the  
250 prevalence of clinically relevant thoracic vertebral malformations was 4.7% in our hospital  
251 population of Pugs overall, the clinical importance of this diagnosis was negligible in the  
252 other two breeds.

253

254 Hemivertebrae were the most frequently diagnosed vertebral malformation in French  
255 bulldogs and English bulldogs, which is consistent with previous publications (Westworth  
256 and Sturges 2010; Moissonnier et al., 2011; Faller et al., 2014; Gutierrez-Quintana et al.,  
257 2014). Additionally, the most frequent location for hemivertebrae was in the mid thoracic  
258 region (T7-T9; Moissonnier et al., 2011; Faller et al., 2014; Guevar et al., 2014; Gutierrez-  
259 Quintana et al., 2014). In our study, French bulldogs were significantly overrepresented for  
260 hemivertebrae compared to the other breeds, with over 90% of neurologically normal animals  
261 affected and the majority of cases showing multiple hemivertebrae. Interestingly, while  
262 hemivertebrae occurred significantly less common in neurologically normal Pugs,  
263 hemivertebrae accompanied by neurological deficits was diagnosed significantly more often

264 in this breed compared to the two other breeds. This finding suggests that although  
265 hemivertebrae are less common in Pugs, this type of vertebral malformation is more likely to  
266 be associated with the development of clinical signs in this breed. It is currently unclear why  
267 hemivertebrae are more often associated with clinical signs in Pugs compared to French and  
268 English bulldogs. A recent study proposed a classification system of canine hemivertebrae  
269 into seven different subtypes (Gutierrez-Quintana et al., 2014). Development of clinical signs  
270 in animals with hemivertebrae is thought to have a multifactorial aetiology, with vertebral  
271 instability and vertebral canal stenosis considered to be contributing factors (Westworth and  
272 Sturges, 2010; Moissonier et al., 2011; Dewey et al., 2016). Hemivertebrae can result in an  
273 abnormal angulation of the vertebral column, referred to as kyphosis or scoliosis  
274 (Moissonier et al., 2011; Aikawa et al., 2014; Faller et al., 2014; Guevar et al., 2014).  
275 Recent studies have suggested that severity of kyphosis is a key factor in the development of  
276 clinical signs in dogs with hemivertebrae and that a certain degree of vertebral kyphosis must  
277 be exceeded before clinical signs are likely to occur (Moissonier et al., 2011; Guevar et al.,  
278 2014). Although beyond the scope of this study, it is possible that Pugs are affected by a  
279 different subtype of hemivertebrae which results in more severe kyphosis. Further studies are  
280 therefore needed to evaluate the influence of breed on hemivertebra subtype and the influence  
281 of hemivertebra subtype on the degree of vertebral kyphosis.

282

283 Pugs were significantly more often diagnosed with thoracolumbar transitional  
284 vertebrae compared to French bulldogs and English bulldogs. In almost one third of  
285 neurologically normal Pugs, T13 demonstrated characteristics of both thoracic and lumbar  
286 vertebrae, including unilateral or bilateral absence of ribs and the presence of rudimentary  
287 transverse processes. Although transitional vertebrae are not considered a direct cause of  
288 spinal cord dysfunction, these anomalies have been associated with alterations in vertebral

289 biomechanics and can complicate the approach of routine spinal surgeries (Morgan et al.,  
290 1968; Flückiger et al., 2006; Westworth and Sturges, 2010).

291

292 Spina bifida refers to failure of closure of one or more vertebral arches over the spinal  
293 cord. It is categorised based on the level of neuroectoderm involved, and subtypes include  
294 aperta (open), cystica (closed) and occulta (hidden; Song et al., 2016). It has been reported in  
295 a variety of breeds and is probably related to genetic and environmental causes (Wilson et al.,  
296 1979; Song et al., 2016). Less severe malformations are commonly encountered without  
297 clinical signs, with malformations typically found incidentally on diagnostic studies (Song et  
298 al., 2016). Our study reported that spina bifida occulta was an infrequent finding in English  
299 and French bulldogs as only one case identified among these dogs, which is similar to the  
300 findings of previous studies of comparable populations (Gutierrez-Quintana et al., 2014). In  
301 contrast, in our study, Pugs were affected by thoracic spina bifida occulta significantly more  
302 often than other breeds and this abnormality was found exclusively at T1. It is currently  
303 unclear why spina bifida occulta was only present at T1 and what the clinical relevance of  
304 this finding may be. This information should however be taken into account when evaluating  
305 imaging studies of Pugs with suspected spinal disease.

306

307 Our study was limited by its retrospective design which meant the majority of this  
308 population of dogs did not receive a neurological examination. Therefore, we cannot exclude  
309 the possibility that a number of animals developed clinical signs relating to vertebral  
310 malformations later in life. However, the retrospective study design enabled the inclusion of a  
311 large population of dogs. Furthermore, neurologically normal animals underwent CT  
312 imaging, while clinically affected dogs underwent MR imaging. Both advanced imaging  
313 techniques are associated with specific advantages and disadvantages and differ clearly in

314 their diagnostic potential for imaging the bony vertebral column and the parenchymal spinal  
315 cord. Therefore, we decided not to compare imaging findings of affected and unaffected dogs  
316 directly. Although not evaluated in this study, further classification of hemivertebra subtype  
317 might have determined whether a specific hemivertebra subtype was more prevalent in one of  
318 the studied breeds and if there was an association with different degrees in spinal kyphosis. A  
319 previous study has demonstrated differences in hemivertebra subtyping when survey  
320 radiographs and CT were compared (Brocal et al., 2016). It is possible that differences would  
321 also exist when comparing MRI and CT. For this reason, a comparison of hemivertebra  
322 subtypes in affected and unaffected dogs was not attempted in our study. It is unclear whether  
323 a classification system designed to evaluate specific bony vertebral body abnormalities could  
324 be used reliably for MRI.

325

## 326 **Conclusions**

327 There is a high prevalence of vertebral malformations in neurologically normal  
328 ‘screw-tailed’ brachycephalic breeds and there is a significant influence of breed on the  
329 prevalence of each type of malformation. Neurologically normal French bulldogs are  
330 significantly more often diagnosed with hemivertebrae than neurologically normal Pugs and  
331 English bulldogs, while neurologically normal Pugs are diagnosed with hemivertebra  
332 significantly less frequently than neurologically normal French and English bulldogs.  
333 However, Pugs are diagnosed with hemivertebra as the cause of neurological deficits more  
334 often than the other breeds evaluated. Further studies are needed to evaluate the influence of  
335 breed on hemivertebra subtype and the influence of hemivertebra subtype on the degree of  
336 vertebral kyphosis.

337

## 338 **Conflict of interest statement**

339 None of the authors has a financial or personal relationship with people or  
340 organisations that could inappropriately influence or bias the content of this paper.

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399 Fig. 1. Sagittal reconstructed (A and B), transverse and three-dimensional reconstructed CT  
400 images illustrating the evaluated thoracic vertebral malformations; hemivertebra (A), block  
401 vertebra (B), spina bifida (C) and a thoracolumbar transitional vertebra (D). Vertebral  
402 malformations indicated by white arrow.

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404 Fig. 2. (A) T2-weighted sagittal and (B) T1-weighted sagittal magnetic resonance images of a  
405 9-month old Pug with a clinically relevant thoracic vertebral body malformation.  
406 Hemivertebra indicated by white arrow.

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